

**State Any Assumptions You Need To Make -- Show All Work -- Circle Any Final Answers**  
**Use Your Time Wisely - Work on What You Can - Be Sure to Write Down Equations**  
**BOLDFACE Variables Are Vectors - Feel Free to Ask Any Questions**

**The Light Bulb and The Room Problem (25,000 points)**

1.) If you look closely at the filament in most light bulbs, you'll see that the wire is usually coiled. If the filament is coiled, then the coil must have an inductance. (a) Find the inductance,  $L_1$ , of the light bulb, given that the filament is 1.00 cm (0.0100 m) long, has a diameter of 4.00 mm (0.00400 m) and has 15 turns.

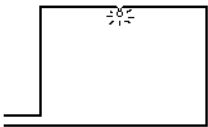


(b) This is a 25 W light bulb, that is it dissipates 25 W of power from its resistance. For  $V = 125$  Volts, find the current,  $i$ , and resistance,  $R$ , of the light bulb.

(c) Find the energy,  $U_L$ , that the inductor  $L_1$  can hold in its magnetic field, with the current  $i$ .

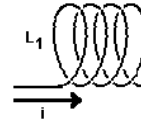
(d) Although the inductor is made up from the very wire that forms the resistor, we can consider  $R$  and  $L_1$  to be in series. Find the time constant of the light bulb. Will it make any difference in how long it takes for the bulb to light? Do you have to state any other assumptions in this part?

(e) Suppose this light bulb in a room is wired so that the current carrying wire makes a big rectangular loop, 3.00 m x 5.00 m. Find the inductance  $L_2$  of this loop.  $L_1$  and  $L_2$  will be in series. Which inductance has the bigger impact on the circuit?



**Mutual Self-Admiration Society Meeting (25,000 points)**

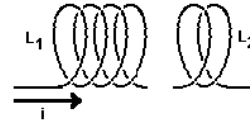
2.) A current  $i = 1.00$  A flows through a 400 loop inductor,  $L_1 = 44.4$  mH. (a) Find the flux  $\Phi_B$  of the magnetic field inside.



(b) Do you have enough information to find the magnitude of the B-field given  $\Phi_B$  from (a)? To find the B-field using the solenoid equation? In each case, either state what else you'd need to know or find B.

(c) If the current was suddenly introduced into the inductor  $L_1$  in 0.0100 s, find the self-induced emf.

(d) Nearby there is a second inductor,  $L_2 = \frac{1}{2} L_1$ . If  $L_2$  has only 200 loops, find the mutual inductance coefficient,  $M$ , between the two coils and the emf induced in  $L_2$  by the current  $i_1$  from (c).



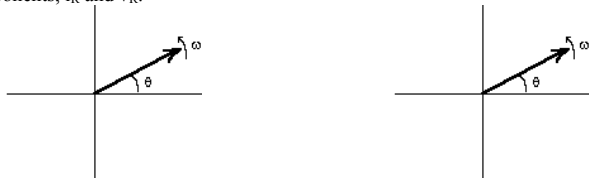
(e) If these two coils were part of a transformer, and the primary ( $L_1$ ) voltage was 110 V 60 cycle A.C., what would be the voltage on the secondary side?

**“Phasors Set on Stun, Captain!” (25,000 points)**

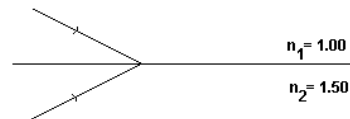
3.) An RLC circuit contains the following elements:  $R = 1000 \Omega$ ,  $C = 1000 \text{ pF}$  and  $L = 1000 \text{ mH}$ . It is driven by an AC generator with  $\omega = 377 \text{ rad/s}$ . (a) Find the capacitive and inductive reactances,  $X_C$  and  $X_L$ .

(b) Find the impedance,  $Z$ , for the circuit. For what value of  $\omega$  is the impedance a minimum?

- (c) If the vector in the phasor diagram on the left represents  $I_L$ , sketch in  $V_L$  and show the relevant instantaneous components,  $i_l$  and  $v_l$ . *Don't worry about the scales of the graphs.*  
 (d) If the vector in the phasor diagram on the right represents  $I_R$ , sketch in  $V_R$  and show the relevant instantaneous components,  $i_r$  and  $v_r$ .

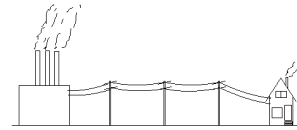


Two light rays hit an air-glass boundary at  $\theta = 60^\circ$ . Make your calculations and show on the diagram what happens to the refracted and reflected rays of (d) the light ray coming from the air and (e) the light ray coming from the glass.



**Power to the People! (35,000 points)**

4.) (a) Two parallel power lines each carry 480. A of current in the same direction. If the cables between two power poles are 85.0 m long and are separated by a distance of 3.50 meters, find the magnetic force between the two power lines, and indicate whether they are attracted or repelled. *For simplicity's sake, treat this as D.C. in this part, even though we know that the power lines are really A.C.*

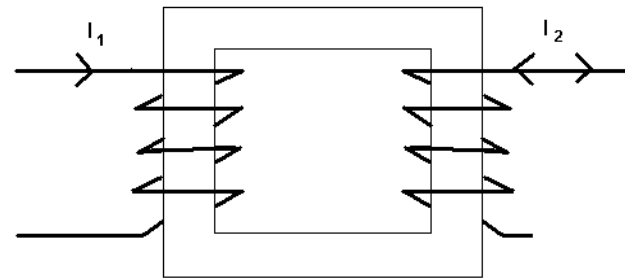


(b) At the house of a mad scientist, Dr. Fyl, the 480. A is used at 118 V A.C. to power his cathedral of Micron Millennia Pentium computers. The power plant is 25.0 km away, and 50.0 km of wires (*to and from*) has a total resistance of  $22.5 \Omega$ . If 480. A runs through the wires, find the efficiency of this power distribution system.

(c) If instead, the electricity is set at 118,000 V A.C. on the power lines, find the new efficiency of the power distribution system.

(d) The voltage is changed by a step-down transformer from 118,000 volts to 118 volts. The secondary coil has  $N_2 = 1000$ . turns. How many turns does the primary loop have?

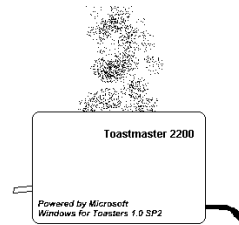
(e) Our transformer is sketched below – note that both sides have the same number of turns so as not to suggest an answer for (d)! If at some time  $t_0$  that the primary current  $I_1$  is increasing and going to the right as shown, then explain whether the induced current of the secondary,  $I_2$ , goes to the LEFT or to the RIGHT.



**“Care For Some Toast?” THE TOASTER IN THE BBC TV SHOW RED DWARF (35,000 pts.)**

5.) (a) A toaster generates Joule heating at a rate of 855 W when plugged into a 125 volt D.C. power source. This results in a current of  $I = 6.84 A$ . The nichrome wire used in the heating element is a high resistance wire, but still the entire heating element only has a resistance of  $R = 18.3 \Omega$ . The heating element can be unfolded to be a single coil 0.500 cm in diameter and 45.0 cm long, with 480. turns. Find the inductance,  $L$ , of this coil.

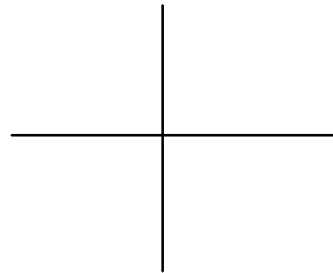
NOTE: If you do not get an answer to (a), use  $L = 252 mH$  in parts (b) - (e).



(b) If this toaster into an AC wall outlet, with  $V_{rms} = 125 volts$  and  $f = 60.0 Hz$ , find the inductive reactance,  $X_L$ , of the heating element.

(c) Sketch a single phasor diagram showing  $v_R$ ,  $v_L$ , and the current,  $i$ .

	"In Use" Equation	"By Geometry" Equation
R	$V = IR$	$R = \frac{\rho L}{A}$
C	$Q = CV$	$C = \epsilon_0 \frac{A}{d}$ (Parallel Plate Capacitor)
L	$L = \frac{N\Phi_B}{I}$	$L = \frac{\mu_0 N^2 A}{l}$ (Air-Core Solenoid)

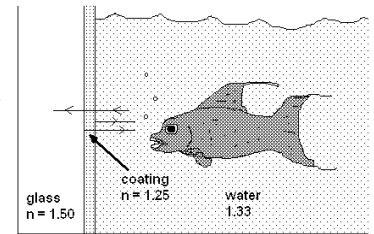


(d) The heater element can be thought of as being a resistor and an inductor in series. What is the time constant of this RL circuit?

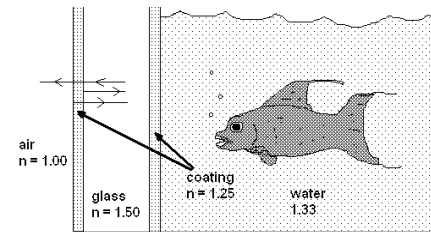
(e) Use the impedance to find  $I_{max}$  for the toaster. There is no capacitive nature to this circuit.

**Fish Stories (50,000 points)**

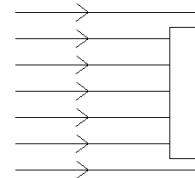
6.) (a) A fish lives in fresh water,  $n = 1.33$ , in a fish tank made of glass,  $n = 1.50$ , that has an acrylic coating on the inside,  $n = 1.25$ . The fish tank is lit with a sodium light, whose wavelength in air is  $\lambda = 555 nm = 5.55 \times 10^{-7} m$ . If the acrylic coating is a half-wave coating, will the fish see its reflection from the inside surface of the glass?



(b) If a second acrylic coating is applied to the outside of the glass, where it meets the air, should this coating be quarter-wave or half-wave, if the fish is going to NOT see its reflection from the outside surface of the glass?



(c) Consider a flat slab of glass ( $n = 1.55$ ). Parallel light rays (in air) come in perpendicular to the surface. If the thickness of the glass is  $(1000 + \frac{1}{4}) \lambda_m$ , would the reflections be maximized or minimized?



(e) A light ray in air comes in from the left and strikes a parallel-plate slab of glass  $A$  of thickness  $d$ . The dashed line shows the path the light ray would have gone if no glass is there. First, sketch in the way the transmitted rays are offset after passing through the glass  $A$ . Second, sketch whether or not the offset ray goes back to its original path if a second identical slab of glass  $B$  is set parallel to  $A$ . There are no numbers to calculate in this problem, but of course the index of refraction of the glass is higher than the index of refraction of air ( $n = 1.00$ ). Show all relevant lines in your sketches.

